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ACCURACY ANALYSIS OF VEHICLE POSITIONING USING GPS AND GLONASS DATA

Summary. The article presents a new computational strategy for determining the positioning accuracy parameter in car navigation, based on a multi-receiver solution of the SPP code method. The experiment was conducted in kinematic mode using five GNSS receivers mounted on the roof of the vehicle. These receivers recorded code observations from the GPS and GLONASS systems at a frequency of 1 Hz. For each receiver, the position was determined separately using the SPP code method based on GPS measurements, GLONASS measurements, and combined GPS/GLONASS measurements. The calculated positions were compared with the reference trajectory obtained using the PPP (Precise Point Positioning) technique. The results of the experiment demonstrate the benefits of multi-system positioning. The average RMS errors for geodetic coordinates (B, L, h) were: GPS – 0.21 m, 0.53 m, 2.06 m; GLONASS – 1.34 m, 1.83 m, 1.78 m; GPS/GLONASS – 0.34 m, 0.73 m, 1.51 m. These results indicate that the combined GPS/GLONASS solution reduces the total positioning error compared to GLONASS alone. In addition, the combined solution improves only the vertical component, but it worsens the horizontal accuracy compared with GPS alone. The accuracies obtained (RMS in the order of meters) are many times better than

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the 20 m limit specified for road navigation systems, which proves the practical usefulness of the developed method.

Keywords: accuracy, car navigation, GPS, GLONASS, GNSS

1. INTRODUCTION

GNSS satellite systems are widely used in air, sea, and land navigation [1]. In land navigation, an important application is car navigation [2], with particular emphasis on determining the position, speed, and acceleration of a moving object [3]. Initially, only the GPS navigation system was used to determine the coordinates of a car's movement [4], but now all global GNSS systems are used in car navigation [5]. The standard GNSS positioning model for car navigation is based on the SPP code method [6]. The SPP code method is used in both static and kinematic GNSS measurements to determine the coordinates of an object [7, 8]. The observation model of the SPP code method is based on the measurement of at least 4 pseudoranges between the position of the GNSS satellite and the position of the mobile receiver located in the car [9]. In addition to the observed pseudoranges, it is necessary to know the position of the satellite at a given moment in time, the time of transmission of the satellite signal from the satellite, and the time of reception of the satellite signal by the receiver [10]. Furthermore, it is crucial to properly model systematic errors occurring in code measurement, such as: ephemeris error, satellite clock error, ionospheric and tropospheric correction, hardware delay for the satellite, relativistic correction, multipath effect, etc. [11]. The application of the SPP code method in car navigation will be shown in the literature review in subsection 1.1.

1.1. Related works

It is worth starting the literature review with the requirements for GNSS satellite systems in terms of their practical application in car navigation. Based on [12], it can be concluded that the accuracy requirements for road transport are as follows:

- navigation and traffic control up to 20 m,
- road accident alerts up to 30 m,
- transport management up to 1500 m,
- automatic notification of scheduled bus stops up to 30 m,
- vehicle guidance and control up to 50 m,
- collision avoidance for critical situations up to 5 m,
- accident data collection up to 30 m,
- infrastructure management up to 10 m,
- collision avoidance for control up to 1 m.

The study [12] shows that the accuracy of determining the position of a car cannot exceed 20 m. The specified accuracy requirements are a reference for other publications from the state of the art analysis, in which the SPP code method was used to determine the position of a car. Thus, in [13], the results of the positioning accuracy of a small agricultural vehicle used on coffee plantations in Brazil are presented. During the research, the average positioning accuracy was 1.42 m horizontally and 7.12 m vertically. Subsequently, in [14], the results of simulations to determine the position of a car in an urban canyon and in a heavily built-up area were

presented. In particular, a model for collecting and exchanging GNSS data from moving cars and an algorithm for determining the multipath effect for GNSS measurements were presented. In the worst-case scenario of a simulation in a heavily urbanized area, the accuracy of car positioning, expressed by the RMS error, falls below 20 m. Another publication [15] investigated the usefulness of GNSS receivers for monitoring car collisions. The accuracy of coordinate determination measured by CEP error was 2.5 m, although errors of the order of 10 m occurred during the 24-hour session. This means that the SPP method may prove insufficient to improve safety in traffic management. However, in [5], the possibility of using GNSS observations to improve kinematic positioning in road transport, especially in urban canyons. The tests achieved a positioning accuracy of better than 5 m. The study utilized GNSS data, LIDAR data, a camera, and sound sensors. The next publication [16] showed the possibility of using the SPP code method and other GNSS positioning methods for automatic driving of cars with built-in sensors and applications. The article highlights recommendations, solutions, and technical considerations for the development of such an IT system for cars. Publications [17, 18] present the concept of integrating GNSS data with SPP solutions and the use of cameras or LIDAR sensors to improve kinematic positioning in urban canyons among large buildings. The paper develops an algorithm for detecting GNSS signals that do not reach the receiver located in the car. The results of the research confirm the effectiveness of the developed solution in highly urbanized areas such as Hong Kong. Similar research can be seen in [19], which also integrates SPP GNSS and LIDAR data. In this case, the accuracy of the object's trajectory reconstruction was 8.8 m with the SPP GNSS + LIDAR solution. In turn, article [20] presents the application of a deep learning model for the prediction and correction of SPP GNSS positioning errors in a highly urbanized environment. The study determined the availability of SPP GNSS positioning, which was 100%. The paper [21] investigated the possibility of using Android phones to determine the position of a car while driving. During the research, the accuracy of horizontal coordinates was up to 30 m, and the accuracy of altitude was up to 45 m. The study examined the impact of measurement noise on GNSS code and phase observations. Another study [22] showed the results of applying GNSS data filtering to improve positioning using the SPP code method. The development of algorithms for detecting errors in GNSS code measurements was particularly important. The developed method allows for position determination in dynamic measurements with an accuracy of 8 m. Publication [23] presented the combination of a GNSS sensor and IMU for the purpose of improving dynamic positioning. In addition, a Kalman filter was used to determine the coordinates of the car. The developed method allows for an improvement in the determination of horizontal coordinates by almost 66-68% within SPP positioning. Another paper [24] compared the positioning accuracy of SPP and PPP methods for road navigation in the Philippines. In the case of the SPP method, the accuracy was over 10 m, while with the PPP method it was less than 1 m. Article [25] demonstrates the possibility of using BDS-3 generation satellites for road transport. It also compares the positioning results of SPP with those of the GPS navigation system. Paper [26] develops an improved RAIM algorithm for the RANSAC model. The RANSAC model was tested for SPP positioning in laboratory conditions and in a real dynamic experiment. Article [27] examines the impact of SPP positioning accuracy on road safety. At low traffic volumes, the impact of accuracy can be ignored. However, at high traffic density, A-GNSS assistance systems need to be developed so that the accuracy of kinematic positioning is higher.

The analysis of the current state of knowledge leads to the following conclusions:

- the issue of using GNSS satellite technology in car navigation and road transport in general is quite important,
- GNSS positioning in car navigation in particular can improve road transport safety,

- increasingly advanced algorithms are being used in GNSS positioning in car navigation to improve the accuracy of determining the position of a moving object,
- it should be noted that all global GNSS systems are used on a daily basis in car navigation,
- GNSS positioning in car navigation involves integration with other navigation or imaging sensors.
- single-frequency code-based SPP remains the most popular solution for GNSS positioning in car navigation [16].

1.2. Research Problem

With regard to the presented analysis of the state of knowledge, it can be seen that there is a lack of research on multi-receiver SPP solutions on one car. This applies to both the GPS navigation system itself and combinations of systems, e.g., GPS/GLONASS. Furthermore, the use of several GNSS receivers allows for redundancy in the user's coordinate navigation solution, which is crucial in kinematic measurements. The more coordinate determinations there are, the greater the confidence in the user's position. In addition, it is possible to check the individual readings from each GNSS receiver. Therefore, the main objective of the study was to determine the positioning accuracy parameter in car navigation based on a multi-receiver SPP code solution. In particular, the importance of the combined GPS/GLONASS solution was emphasized in relation to GPS positioning alone and GLONASS separately. It was noted that the SPP GPS/GLONASS solution provides better accuracy than the single determination of SPP GPS or SPP GLONASS. Furthermore, the research was conducted in kinematic mode for five GNSS receivers mounted on the roof of a car. The results obtained are interesting for the mass application of the SPP code method in car navigation.

The article is divided into five main sections: 1. Introduction, 2. Materials and methods, 3. Research results, 4. Discussion, 5. Conclusion. In addition, two subsections have been added to Section 1. A bibliography has also been added at the end of the paper.

2. MATERIALS AND METHODS

To solve the research problem, a methodology was developed, the block diagram of which is shown in Fig. 1. At the beginning, each of the on-board GNSS receivers collects GPS and GLONASS code observations in real time in kinematic mode every 1 s. The GNSS receivers are designated as R0, R1, R2, R3, and R4. The receiver R0 is the central receiver, while receivers R1-R4 are external receivers, as shown in Fig. 2. In addition, receiver R0 is a Septentrio AsteRx2i receiver [28], while receivers R1-R4 are Topcon TPS HiperPro receivers [29]. All GNSS receivers were placed on the roof of the car on a specially prepared metal structure. Receivers R1 and R2 were positioned opposite each other, as were receivers R3 and R4. The distance between receivers R1 and R2, and between R3 and R4, was approximately 1.5 m. Receiver R0, in turn, was located in the center of the beam between receivers R1, R2, R3, and R4. For the geometry of all GNSS receivers, information on the antenna's phase center characteristics was used so that the GNSS observations would be referenced to the antenna's ARP reference point [30].

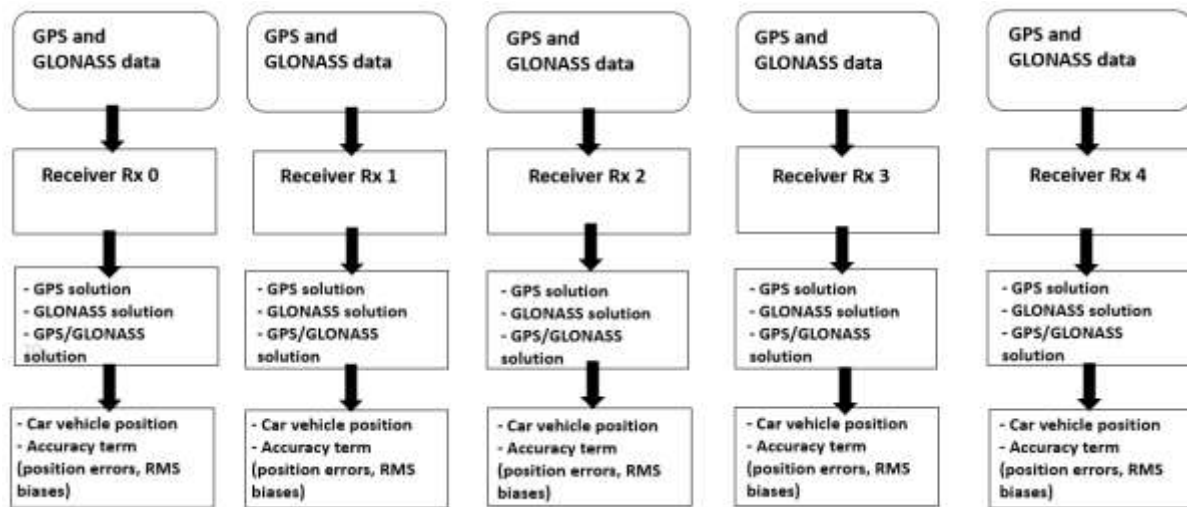


Fig. 1. The flowchart of research methodology



Fig. 2. The on-board GNSS receivers

The car performed a test drive in north-eastern Poland in the Warmian-Masurian Province. The experiment lasted from 08:03:56 to 09:22:18 in 17.09.2015 according to GPS Time. The research for this article was conducted at the EPOD airport in Olsztyn. There were no terrain obstacles, trees, or tall buildings along the car's route. The GNSS signal reached the receivers mounted on the car's roof directly. The speed was approximately 40 km/h and the route was about 20 km long. During the trip, there were 2 stops totaling about 45 minutes. A sketch of the route is shown in Fig. 3.

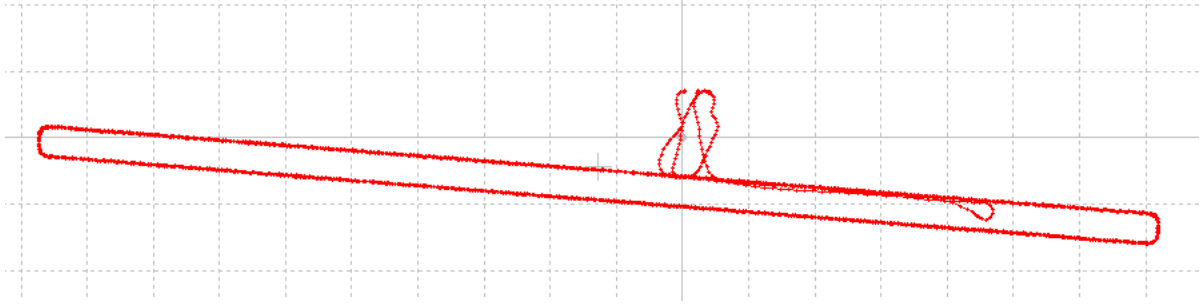


Fig. 3. The rough sketch of the car's route

Based on the attached block diagram, the position of the car was determined based on GPS and GLONASS observations. Ultimately, the SPP code method [31] in RTKLIB v.2.4.3. software [32] was used to determine the coordinates. In RTKLIB software, the processing strategy was configured as follow: elevation mask: 5 degree, ionospheric model: Klobuchar model, tropospheric model: Saastamoinen model, weighting scheme: in function of elevation angle. The coordinates of the car's position for each GNSS receiver were determined in three ways, i.e., from the GPS solution, the GLONASS solution, and the joint GPS/GLONASS solution. Thus, three sets of BLh geodetic coordinates were obtained from each GNSS receiver. In addition, the reference position of the car's trajectory is determined for each GNSS receiver using the PPP measurement technique [33]. In this case, the calculations were performed on the basis of code and carrier-phase observations in the CSRS-PPP software [34, 35]. The reference trajectory of the vehicle from the CSRS-PPP program was determined with high accuracy, i.e., better than 0.05 m for the horizontal components and better than 0.09 m for the vertical component. Then, the results of the BLh geodetic coordinates were compared with each other to determine the position errors [36], as shown in Equations (1-3).

Equations (1-3) describe position errors for each GPS, GLONASS, and GPS/GLONASS solution for a single GNSS receiver in the form:

$$dB_i = \begin{cases} B_{i,GPS} - B_{i,ref} \\ B_{i,GLO} - B_{i,ref} \\ B_{i,GPS/GLO} - B_{i,ref} \end{cases} \quad (1)$$

$$dL_i = \begin{cases} L_{i,GPS} - L_{i,ref} \\ L_{i,GLO} - L_{i,ref} \\ L_{i,GPS/GLO} - L_{i,ref} \end{cases} \quad (2)$$

$$dh_i = \begin{cases} h_{i,GPS} - h_{i,ref} \\ h_{i,GLO} - h_{i,ref} \\ h_{i,GPS/GLO} - h_{i,ref} \end{cases} \quad (3)$$

where:

(dB_i, dL_i, dh_i) – position errors for a single GNSS receiver, based on comparison the each SPP solution and PPP method,

i – GNSS receiver designation, $i = (0,1,2,3,4)$,

$(B_{i,GPS}, L_{i,GPS}, h_{i,GPS})$ – GPS position coordinates for a single GNSS receiver,

$(B_{i,GLO}, L_{i,GLO}, h_{i,GLO})$ – GLONASS position coordinates for a single GNSS receiver,

$(B_{i,GPS/GLO}, L_{i,GPS/GLO}, h_{i,GPS/GLO})$ – position coordinates from the GPS/GLONASS solution for a single GNSS receiver,

$(B_{i,ref}, L_{i,ref}, h_{i,ref})$ – reference coordinates from the CSRS-PPP program for a single GNSS receiver.

In turn, for a system of 5 GNSS receivers, the positioning accuracy of the car is as follows:

$$\begin{cases} dB = \frac{\sum_{i=0}^4 dB_i}{NR} \\ dL = \frac{\sum_{i=0}^4 dL_i}{NR} \\ dh = \frac{\sum_{i=0}^4 dh_i}{NR} \end{cases} \quad (4)$$

where:

(dB, dL, dh) – position errors for a system of 5 GNSS receivers, applies to GPS, GLONASS, and GPS/GLONASS solutions.

NR – number of GNSS receivers, $NR = 5$.

In addition, the RMS statistical error [37] will then be:

$$\begin{cases} RMSdB = \sqrt{\frac{[dB^2]}{N}} \\ RMSdL = \sqrt{\frac{[dL^2]}{N}} \\ RMSdh = \sqrt{\frac{[dh^2]}{N}} \end{cases} \quad (5)$$

where:

$(RMSdB, RMSdL, RMSdh)$ – RMS errors for BLh components for a system of 5 GNSS receivers, applies to GPS, GLONASS, and GPS/GLONASS solutions.

N – number of measurement epochs, $N = 4703$.

Furthermore, using Equations (6-8), we determined the percentage change in the position error spread of the GPS/GLONASS solution relative to the individual results from the GPS and GLONASS solutions:

$$U_B = \begin{cases} \left(\frac{dB_{i,GPS}^{max} - dB_{GPS/GLO}^{max}}{dB_{i,GPS}^{max}} \right) \cdot 100\% \\ \left(\frac{dB_{i,GLO}^{max} - dB_{GPS/GLO}^{max}}{dB_{i,GLO}^{max}} \right) \cdot 100\% \\ \left(\frac{dB_{i,GPS/GLO}^{max} - dB_{GPS/GLO}^{max}}{dB_{i,GPS/GLO}^{max}} \right) \cdot 100\% \end{cases} \quad (6)$$

$$U_L = \begin{cases} \left(\frac{dL_{i,GPS}^{max} - dL_{GPS/GLO}^{max}}{dL_{i,GPS}^{max}} \right) \cdot 100\% \\ \left(\frac{dL_{i,GLO}^{max} - dL_{GPS/GLO}^{max}}{dL_{i,GLO}^{max}} \right) \cdot 100\% \\ \left(\frac{dL_{i,GPS/GLO}^{max} - dL_{GPS/GLO}^{max}}{dL_{i,GPS/GLO}^{max}} \right) \cdot 100\% \end{cases} \quad (7)$$

$$U_h = \begin{cases} \left(\frac{dh_{i,GPS}^{max} - dh_{GPS/GLO}^{max}}{dh_{i,GPS}^{max}} \right) \cdot 100\% \\ \left(\frac{dh_{i,GLO}^{max} - dh_{GPS/GLO}^{max}}{dh_{i,GLO}^{max}} \right) \cdot 100\% \\ \left(\frac{dh_{i,GPS/GLO}^{max} - dh_{GPS/GLO}^{max}}{dh_{i,GPS/GLO}^{max}} \right) \cdot 100\% \end{cases} \quad (8)$$

where:

(U_B, U_L, U_h) – percentage change in the spread of position errors,

$(dB_{i,GPS}^{max}, dL_{i,GPS}^{max}, dh_{i,GPS}^{max})$ – maximum absolute value of position error values from a single GPS solution for each GNSS receiver,

$(dB_{i,GLO}^{max}, dL_{i,GLO}^{max}, dh_{i,GLO}^{max})$ – maximum absolute value of position error values from a single GLONASS solution for each GNSS receiver,

$(dB_{i,GPS/GLO}^{max}, dL_{i,GPS/GLO}^{max}, dh_{i,GPS/GLO}^{max})$ – maximum absolute value of position error values from a single GPS/GLONASS solution for each GNSS receiver,

$(dB_{GPS/GLO}^{max}, dL_{GPS/GLO}^{max}, dh_{GPS/GLO}^{max})$ – maximum absolute value of position error values based on Equation (4).

Equations (1-8) describe the accuracy of car positioning based on GPS, GLONASS, and GPS/GLONASS solutions. This gives us three accuracy results for describing the position of the car's movement. The Scilab v.6.1.1 software was used to calculate the parameters from Equations (1-8) [38]. The calculation results are shown in Section 3.

3. RESEARCH RESULTS

The presentation of the accuracy test results obtained was divided into three parts, i.e., results from the GPS solution, results from the GLONASS solution, and results from the GPS/GLONASS solution. Within the GPS solution, the number of GPS satellites tracked by all GNSS receivers was first shown, as illustrated in Fig. 4. All receivers R0, R1, R2, R3, and R4 tracked between 8 and 11 GPS satellites while the car was in motion. In the first part of the experiment, the number of GPS satellites was the highest.

Next, Figs. 5-7 show the individual position error values (dB_i, dL_i, dh_i) from the GPS solution for all GNSS receivers. The position error values (dB_i, dL_i, dh_i) were calculated according to Equations (1-3). For the B component, the spread of the obtained position errors ranges from -0.99 m to 1.42 m. For the L component, the spread of the obtained position errors ranges from -0.76 m to 1.44 m. Furthermore, for the h component, the spread of the obtained position errors ranges from -4.99 m to 0.19 m. It can be seen that the largest spread of position error values is noticeable for the ellipsoidal height h.

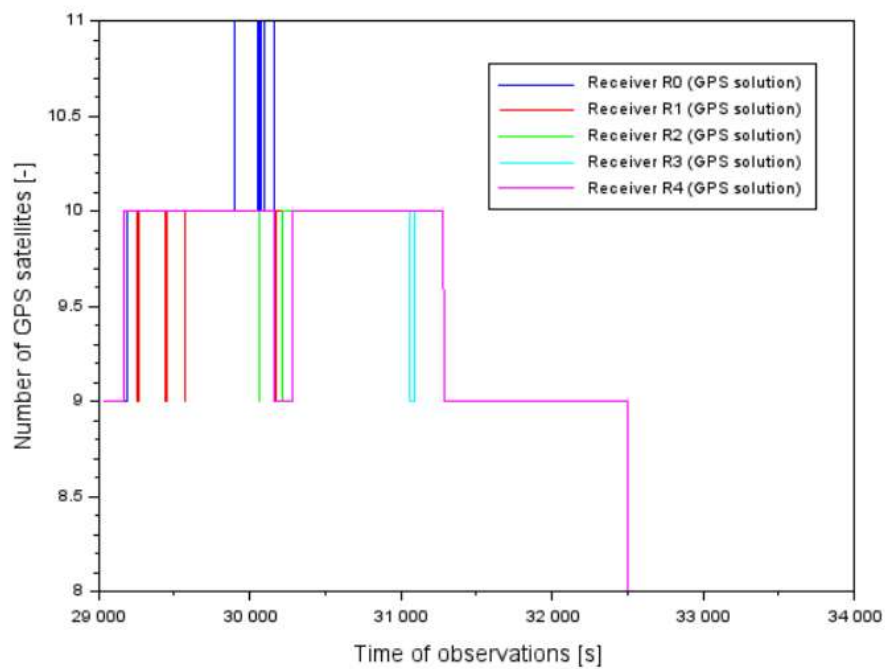


Fig. 4. The number of GPS satellites

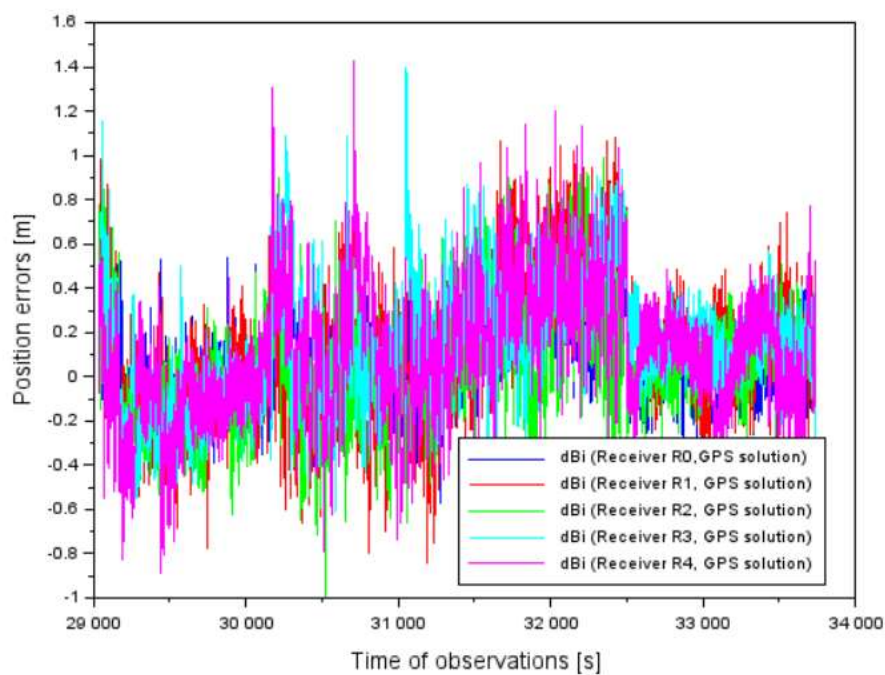


Fig. 5. The position errors along B coordinate from GPS solution for each receiver

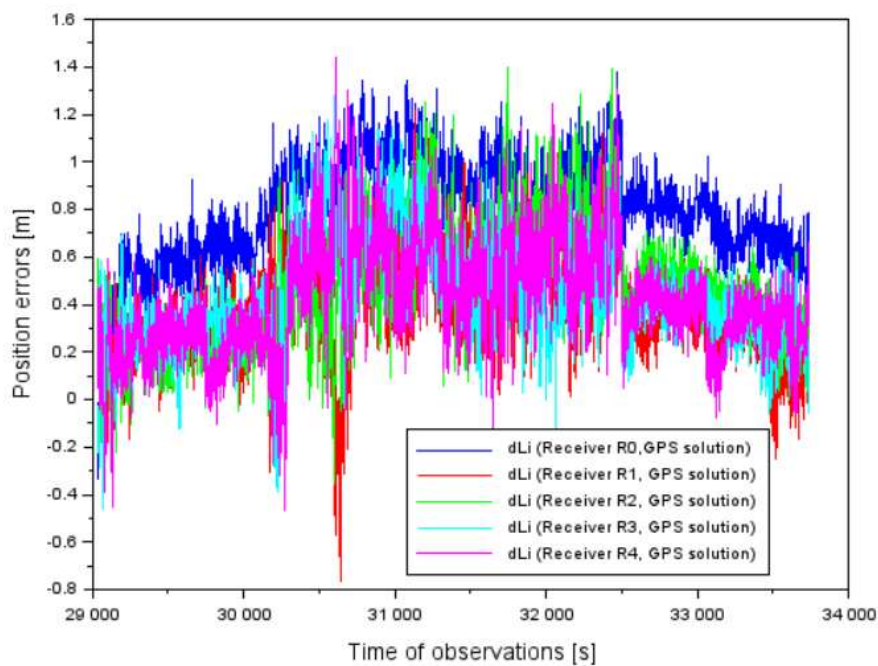


Fig. 6. The position errors along L coordinate from GPS solution for each receiver

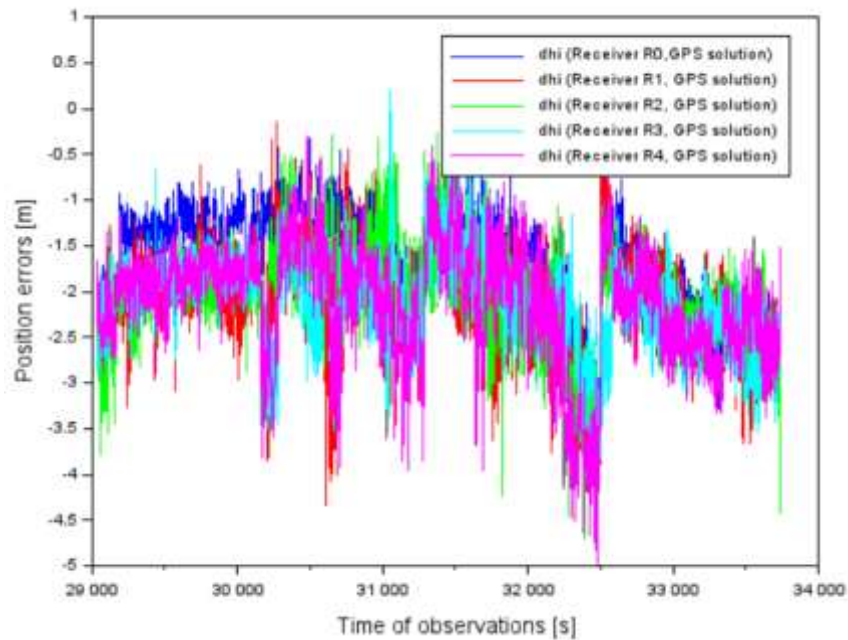


Fig. 7. The position errors along h coordinate from GPS solution for each receiver

The second part of the presentation of results concerns the GLONASS solution. Fig. 8 shows the number of GLONASS satellites tracked by all GNSS receivers. All receivers R0, R1, R2, R3, and R4 tracked between 7 and 10 GLONASS satellites while the car was in motion. The number of GPS satellites tracked was higher than that of GLONASS satellites during the experiment.

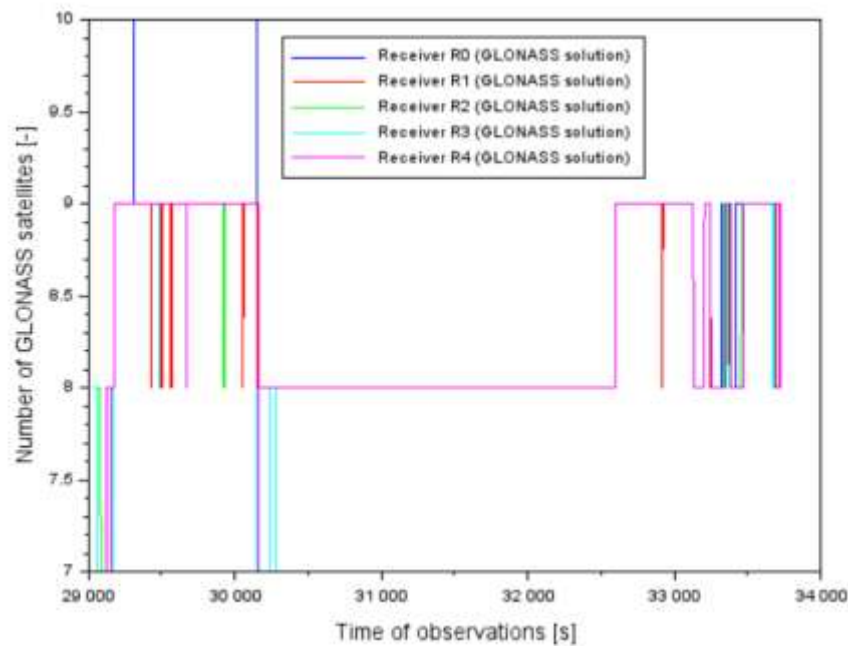


Fig. 8. The number of GLONASS satellites

Figs. 9-11 show the individual position error values (dB_i, dL_i, dh_i) from the GLONASS solution for all GNSS receivers. For the B component, the spread of the obtained position errors ranges from -4.45 m to 2.70 m. For the L component, the spread of the obtained position errors ranges from -4.39 m to 4.62 m. Furthermore, for the h component, the spread of the obtained position errors ranges from -5.83 m to 6.14 m.

Finally, the GPS/GLONASS positioning results were presented. Fig. 12 shows the number of GPS+GLONASS satellites tracked by all GNSS receivers. All receivers R0, R1, R2, R3, and R4 tracked between 16 and 21 GPS+GLONASS satellites while the car was in motion. In the first phase of the kinematic test, the number of GPS+GLONASS satellites was the highest.

Figs. 13-15 show the individual position error values (dB_i, dL_i, dh_i) from the GPS/GLONASS solution for all GNSS receivers. For the B component, the spread of the obtained position errors ranges from -1.43 m to 1.14 m. For the L component, the spread of the obtained position errors ranges from -0.57 m to 1.52 m. Furthermore, for the h component, the spread of the obtained position errors ranges from -4.43 m to 1.09 m.

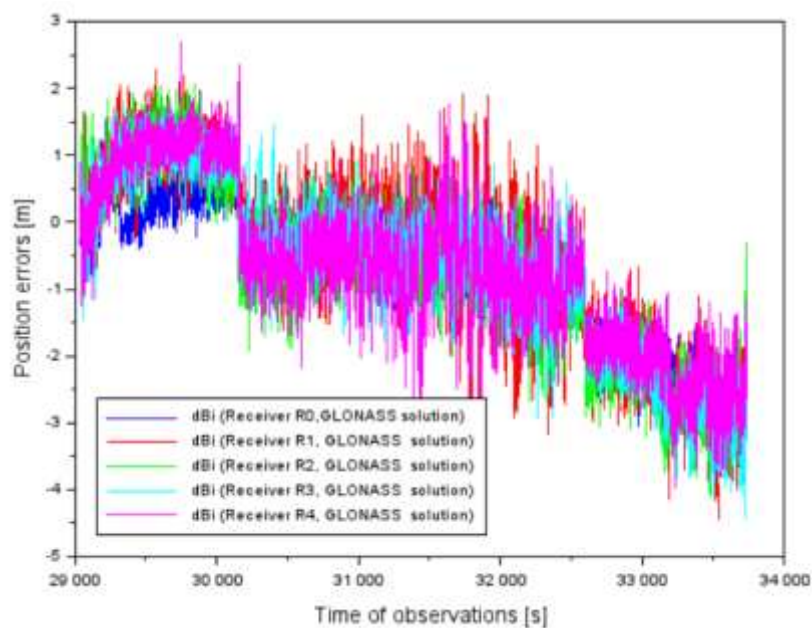


Fig. 9. The position errors along B coordinate from GLONASS solution for each receiver

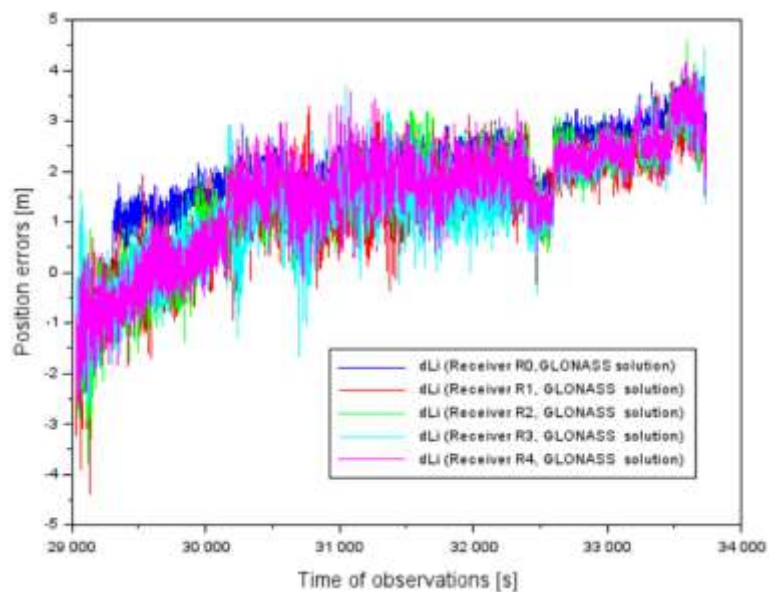


Fig. 10. The position errors along L coordinate from GLONASS solution for each receiver

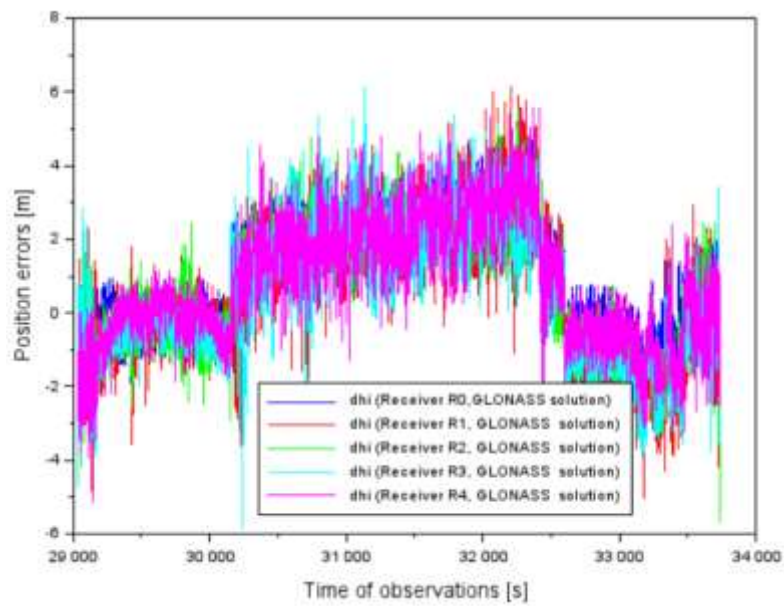


Fig. 11. The position errors along h coordinate from GLONASS solution for each receiver

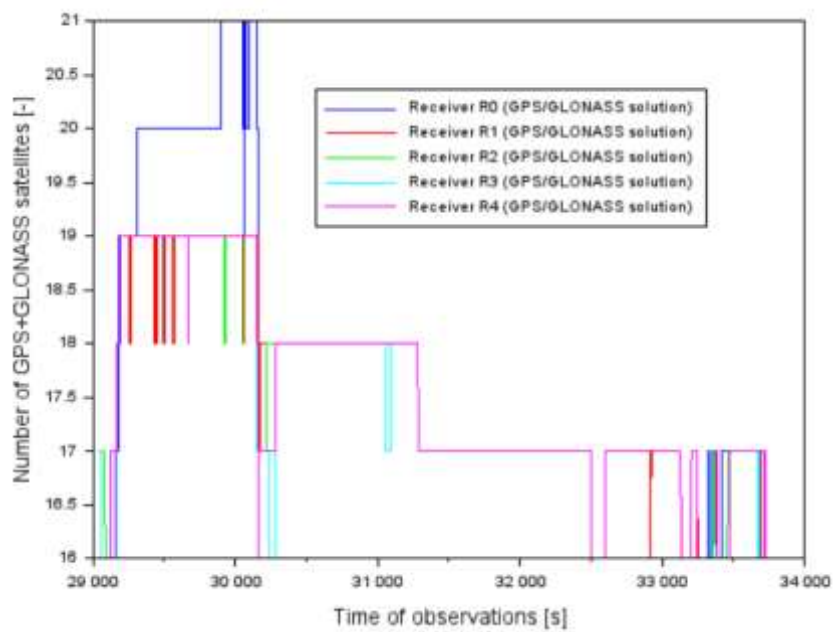


Fig. 12. The number of GPS+GLONASS satellites

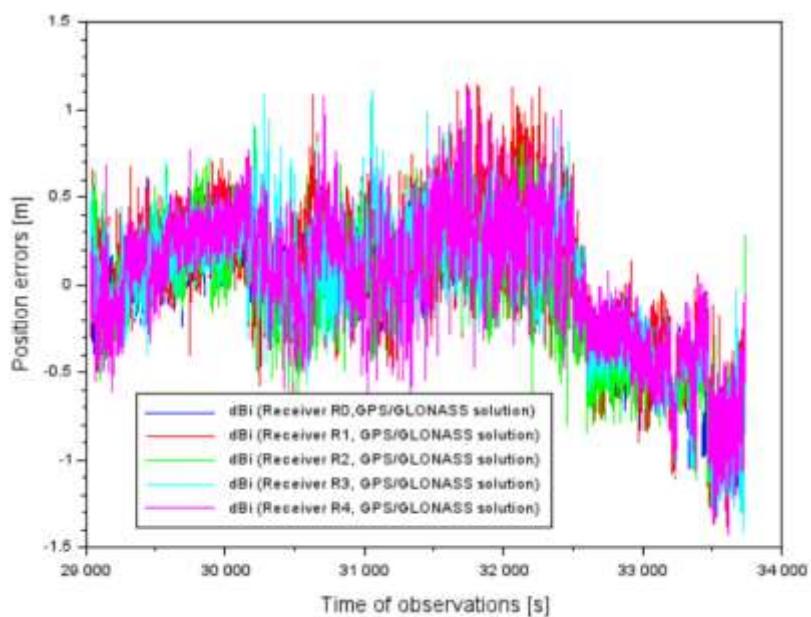


Fig. 13. The position errors along B coordinate from GPS/GLONASS solution for each receiver

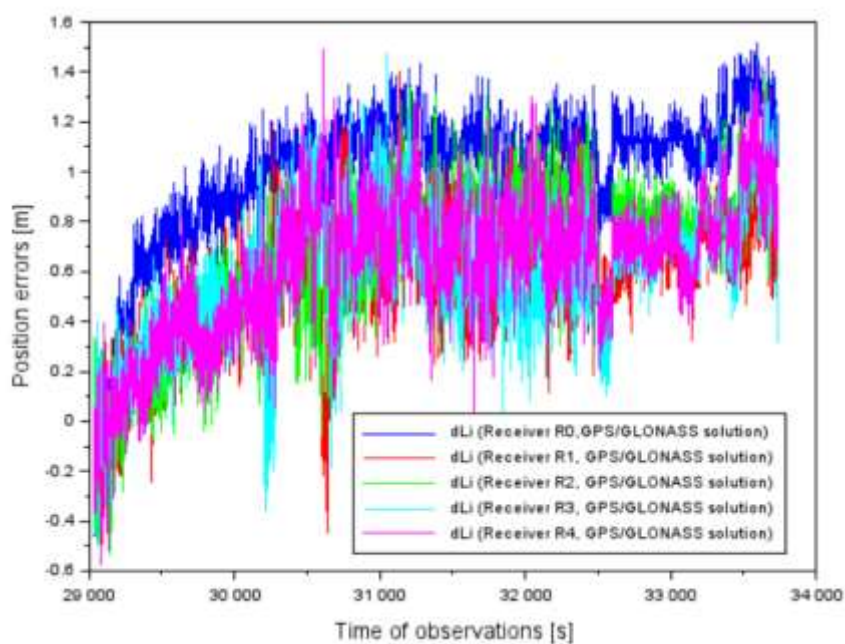


Fig. 14. The position errors along L coordinate from GPS/GLONASS solution for each receiver

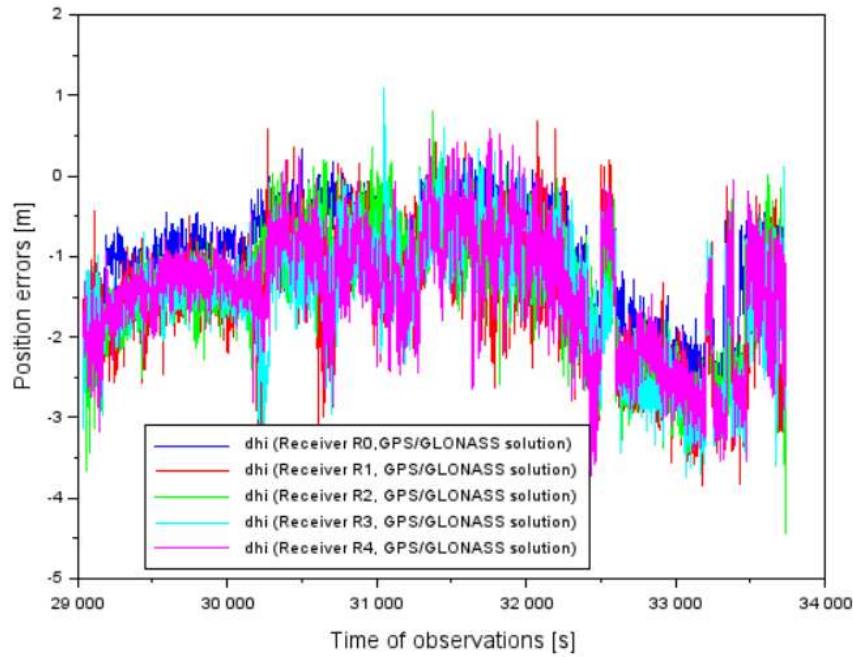


Fig. 15. The position errors along h coordinate from GPS/GLONASS solution for each receiver

4. DISCUSSION

As part of the discussion, the accuracy results calculated according to Equations (4-8) were presented. Figs. 16-18 show the position error results (dB , dL , dh) calculated for the GPS, GLONASS, and GPS/GLONASS solutions. For the GPS solution, the position errors ranged from -0.38 m to 0.64 m for the B component, from 0.04 m to 1.08 m for the L component, and from -3.72 m to -1.05 m for the h component. For the B component, the spread of maximum position error results improved by $U_B = 55\%$ compared to the results shown in Fig. 5. For the L component, the spread of maximum position error results improved by $U_L = 25\%$ compared to the results shown in Fig. 6. For the h component, the spread of maximum position error results improved by $U_h = 26\%$ compared to the results shown in Fig. 7. Furthermore, the RMS errors calculated from Equation (5) for the BLh components for the GPS solution are equal to: 0.21 m for the B component, 0.53 m for the L component, and 2.06 m for the h component.

For the GLONASS solution, the position errors ranged from -3.37 m to 1.54 m for the B component, from -1.92 m to 3.87 m for the L component, and from -2.82 m to 4.41 m for the h component. For the B component, the spread of maximum position error results improved by $U_B = 24\%$ compared to the results shown in Fig. 9. For the L component, the spread of maximum position error results improved by $U_L = 16\%$ compared to the results shown in Fig. 10. For the h component, the spread of maximum position error results improved by $U_h = 28\%$ compared to the results shown in Fig. 11. Additionally, the RMS errors for the BLh components from the GLONASS solution are equal to: 1.34 m for the B component, 1.83 m for the L component, and 1.78 m for the h component.

For the GPS/GLONASS solution, the position errors ranged from -1.08 m to 0.56 m for the B component, from -0.26 m to 1.29 m for the L component, and from -3.07 m to -0.20 m for the h component. For the B component, the spread of maximum position error results improved

by $U_B = 24\%$ compared to the results shown in Fig. 13. For the L component, the spread of maximum position error results improved by $U_L = 15\%$ compared to the results shown in Fig. 14. For the h component, the spread of maximum position error results improved by $U_h = 31\%$ compared to the results shown in Fig. 15. The RMS errors for the BLh components from the GPS/GLONASS solution are equal to: 0.34 m for the B component, 0.73 m for the L component, and 1.51 m for the h component.

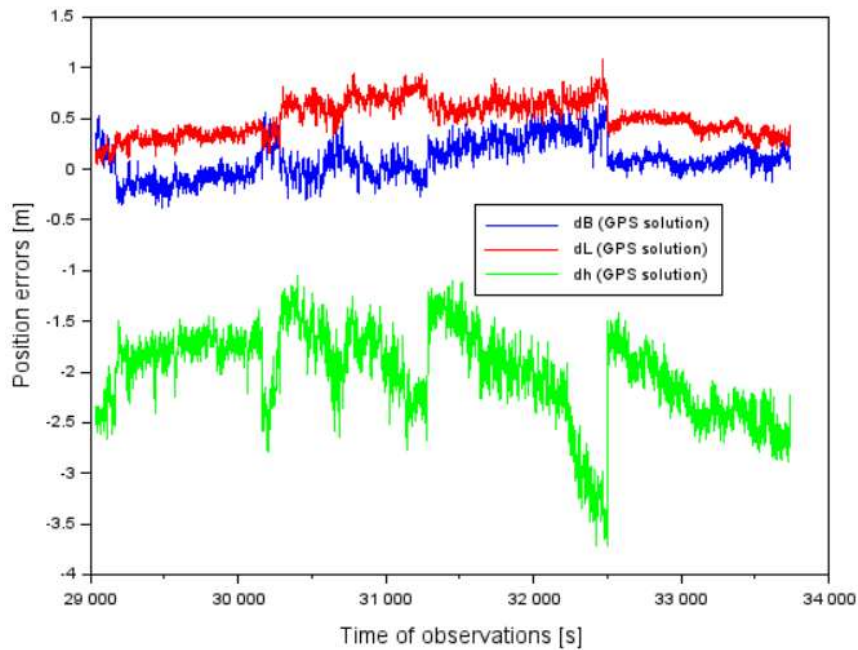


Fig. 16. The final position errors for BLh coordinates from GPS solution

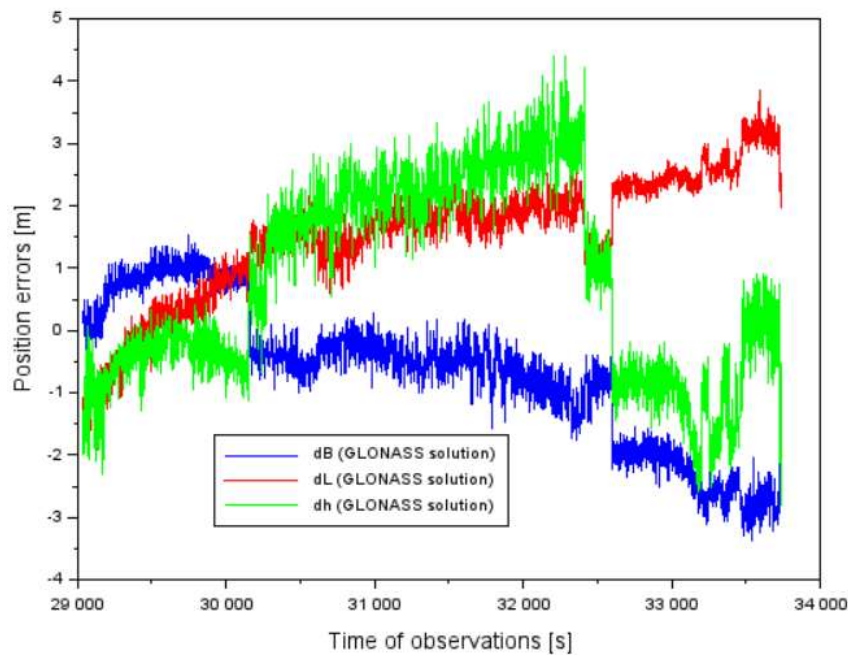


Fig. 17. The final position errors for BLh coordinates from GLONASS solution

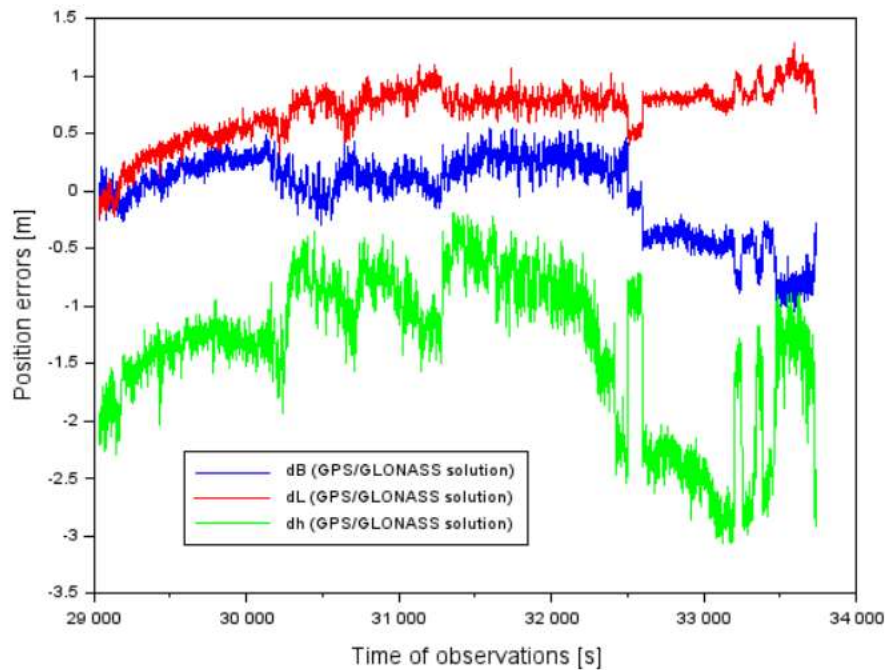


Fig. 18. The final position errors for BLh coordinates from GPS/GLONASS solution

All RMS errors are summarized in Table 1. The GPS/GLONASS solution significantly improved the determination of the ellipsoidal height h compared to the GPS and GLONASS solutions alone. Furthermore, the GPS/GLONASS solution improved the determination of all BLh coordinates compared to the GLONASS solution alone.

Tab. 1

Characteristic of RMS errors

Coordinate	GPS [m]	GLONASS [m]	GPS/GLONASS [m]
B	0.21	1.34	0.34
L	0.53	1.83	0.73
h	2.06	1.78	1.51

The discussion also referred to the accuracy results obtained in relation to the analysis of the state of knowledge. It is worth noting that the obtained GPS, GLONASS, and GPS/GLONASS positioning accuracy results meet the standards for car navigation, as shown in publication [12]. In addition, thanks to the presented research method, it was possible to increase the accuracy of kinematic positioning of a car, similarly to the works [5, 13-27]. Furthermore, this work uses the SPP code positioning method, as in works [5, 13-27]. The article is part of a trend in research on the use of Multi-GNSS observations in kinematic positioning in road transport, as in works [5, 25]. The research was conducted using only GNSS receivers without additional sensors or navigation systems, which directly refers to publications [5, 12, 13, 14, 15, 16, 24, 25].

5. CONCLUSION

The research conducted confirmed the usefulness of the proposed approach. Based on the analysis of the results, the following conclusions can be drawn:

- the multi-receiver SPP solution ensures redundancy of GNSS measurements, which increases the accuracy of the determined position of vehicle,
- the use of a hybrid SPP (GPS+GLONASS) significantly reduces positioning errors compared to standalone GLONASS, confirming the higher accuracy of the combined solution,
- the positioning accuracy achieved (RMS errors at the level of single meters) is several times better than the required 20 m for car navigation, which proves that the method meets accuracy standards and is practical for use in automotive systems,
- the method based solely on GNSS code observations (without additional on-board sensors) is simple to implement and attractive for car navigation systems, thus increasing the safety and reliability of positioning in road transport.

In the future, the authors plan to expand their research to include SBAS and DGPS positioning methods in car navigation. In addition, other GNSS systems, such as Galileo and BeiDou, will be used for the vehicle's kinematic positioning. This study did not use the Galileo and BeiDou systems due to the age of the receivers, which posed a certain limitation to the research. However, in the future, the authors plan to use all available global GNSS systems for vehicle positioning.

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